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MINISTRY OF SUPPLY

ARMAMENT RESEARCH ESTABLISHMENT

SYMPOSIUM

ON

THE PHYSICAL EFFECTS OF ATOMIC WEAPONS

PAPER No. 11

Visible Radiation from an Atomic Bomb Explosion

J. Corner

SECRET

Visible Radiation from an Atomic Bomb Explosion.

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1. Nature of the radiating source

For two or three seconds after the explosion of an air-burst atomic bomb, visible radiation is emitted from a white-hot globe, the "ball of fire", centred on the place where the bomb burst. Before dealing with the size and effective temperature of this globe we describe first how it is generated.

The shock of the nuclear explosion passes through the material of the bomb and is transmitted to the air as a very intense shock whose passage raises the air to an extremely high temperature, of the order of a million degrees K. It is this shocked air which gives the visible radiation.

As the shock passes away from the bomb, its ability to heat the air decays rapidly. Thus the outer boundary of the "ball of fire" does not continue to expand indefinitely. After a while the edge expands only because of the outward motion of the hot gases themselves. The gases are meanwhile losing energy by thermal radiation, and the recognisable ball ceases to expand after about a third of a second. The transport of energy by thermal radiation is very rapid in the earliest stages and is indeed a controlling factor in the initial motion of the boundary of the ball of fire. However, the radiation is then of the nature of soft X-rays and is rapidly absorbed. For an observer at a few hundred yards the observable phenomena can be described quite well as an expanding and cooling ball, radiating as a black body.

After a few seconds the ball ceases to be visible to the eye and the hot and buoyant gases rise, sucking in cold air as they go, to form the so-called "smoke cloud".

When a bomb is exploded underwater at depths of order 100 feet, the bubble formed is still hot enough to radiate as it breaks through the surface. The radiation is of course much weaker in this case and is a trivial hazard compared with the radioactivity.

2. Radius and temperature of the ball of fire

Observations of the radius as a function of time were made at the Trinity and Able shots and were reasonably consistent. The temperature was measured photographically at Trinity and several methods were attempted at Able, while a theoretical curve was produced at Los Alamos. The results seemed at first to be extremely contradictory. Mr. Woodcock (of A.R.E.) has been looking into this matter and has been able to reconcile the results except that a gross error by one of the previous workers is implied.

The results are shown in Figs. 1 – 4. The radius of the ball of fire (Fig. 1) increases quite steadily for about a third of a second. The final radius is about 300 yards. The transition curve from the steady expansion to the part of constant radius is only a guess, but is not an important point. The behaviour of the radiation temperature (Figs. 2 & 3) is more involved. The solid curve of Fig. 3 is the final result of Woodcock's analysis. It represents quite well the total radiation deduced from observations at 18 miles from the Bikini bomb (dotted curves of Fig. 3) and it joins smoothly to the temperatures recorded photographically at earlier stages of the phenomenon. The Los Alamos theoretical results (curve II of Fig. 2) are not reliable beyond their minimum, except in general form, and to this extent they agree reasonably well with curve III (Fig. 2), obtained by direct photography of the ball at Bikini, and with the solid curve of Fig. 3. The rise of temperature during the very earliest phase in curve III of Fig. 2 is presumably due to the finite resolution of the camera overestimating the radius of the light source at this time. The Trinity bomb was photographed and the results (curve I of Fig. 2) are difficult to reconcile with any other data. It is presumed that there was an error in the processing of the film, as was indeed the belief of the photographers at Bikini.

We conclude that the radiation temperature falls rapidly in the first 10 milliseconds, with a main phase of almost constant temperature lasting for almost a second. The temperature then decays steadily.

3. Energy radiated

The temperature of the radiator is, for the greater part of the time, about the same as that of the outer layers of the sun. The ultra-violet light at less than 3000°A will be strongly absorbed in the atmosphere, and if we omit this we get an estimate for the total amount of effective energy radiated. In this way Mr. Woodcock has found 8×10^{12} calories, or, if we define a kiloton of T.N.T. as 10^{12} calories, the radiated energy is 8 kilotons. This is divided almost equally between visible radiation and infra-red. 8 kilotons is about 40 per cent of the energy released in the original nuclear explosion.

Fig. 4, taken from a report by Mr. Woodcock, shows his best estimate of the outward flux of energy, in wavelengths greater than 5000 A, as a function of time from explosion.

4. Ignition by radiation

Several workers have attempted to calculate the conditions under which wood or curtains could be ignited by the radiation alone. These methods agree with observations in Japan and at Bikini in showing that scorching is possible at distances of order two miles, depending on the specific heat of the material and its reflection coefficient. The blast would usually be more important as a cause of indirect fires. This view is supported also by experiments with wooden specimens exposed to the Trinity bomb.

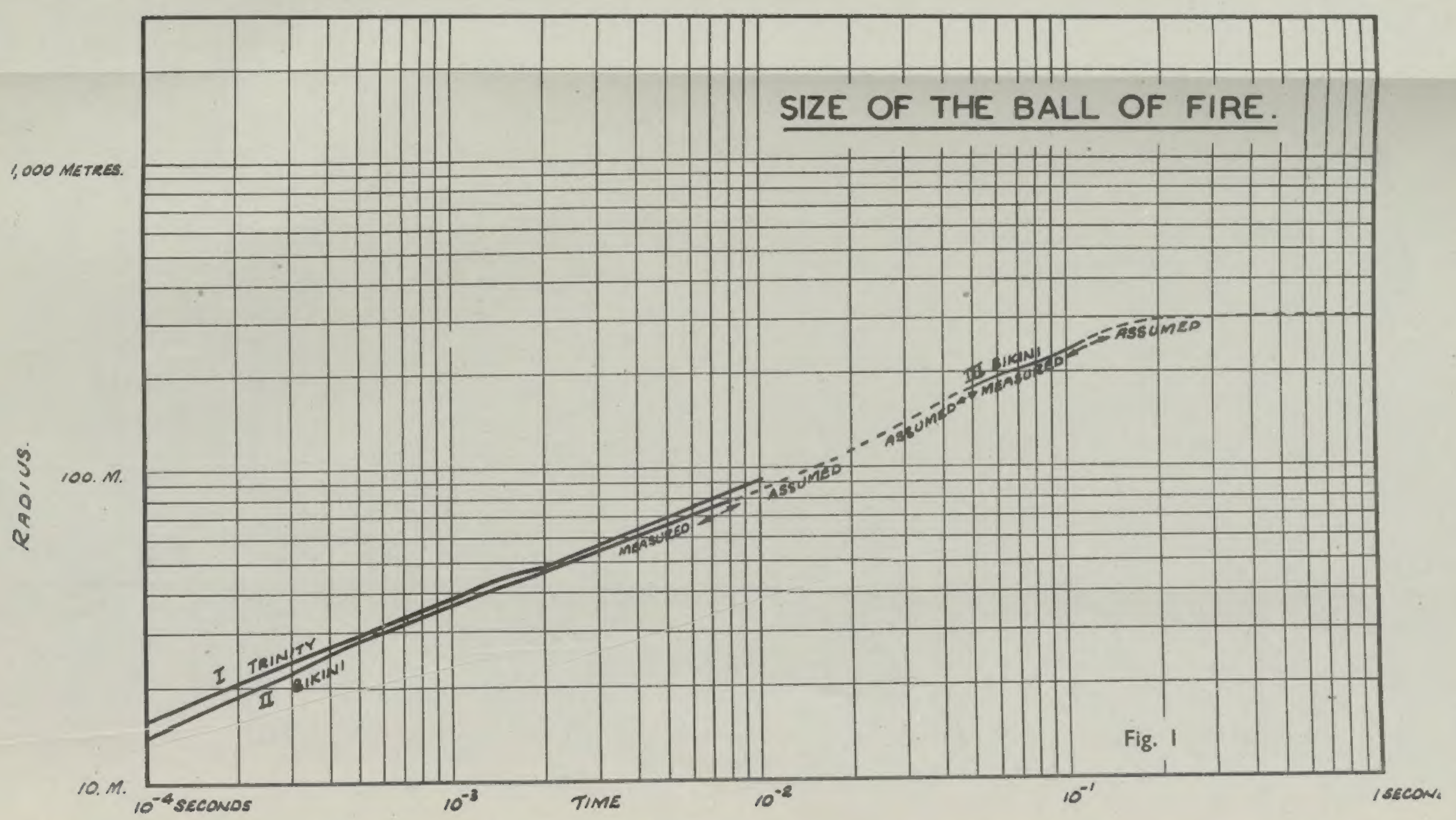
5. Flash-burn

In practice the most important effect of the radiation is the "flash-burn" produced on human skin exposed to the radiation. As we have seen, the time-scale of the phenomenon is of order two to three seconds, so the involuntary closing of the eyes protects them from especially serious results. Dr. Pochin will describe radii for flash-burn of various degrees. Here it will suffice to mention that the effects extend to greater distances than do those produced by the gamma rays and neutrons. Fortunately even the lightest of screening is a complete protection against burns.

6. Rain and fog.

In a clear atmosphere the radiation travels away in straight lines without much absorption. If we now add rain or water-drops the radiation is scattered again and again, often ending up by being absorbed in the ground or returning to the ball of fire. In the latter case the radiation reappears later, since radiation is the main mechanism by which the ball cools. Scattering therefore increases the length of path of the radiation and so enhances the effect of any absorbing agents present, and if there are smoke particles present among the water,as in a town fog, the attenuation of the thermal radiation is very great. Of course the smoke particles now become hot and emit radiant energy, but as their temperature is lower than that of the ball of fire much of the energy is trapped in the infra-red absorption bands of the water vapour, present at saturation pressure in fog or rain. Thus mist and especially a smoky fog will cut down the risk of flashburn.

An attempt has been made to estimate the effect of smoke and fog on the radius to which flashburn is experienced. An essential feature is the transfer of energy by the smoke particles into wavelengths at which it is strongly absorbed by the water vapour present; this feature requires for its mathematical description an absorption coefficient varying strongly with wavelength. The problem is being studied in the case of spherical symmetry, by using Chandrasekhar's first approximation. Full allowance is made for the varying size of the ball of fire.


SIZE OF THE BALL OF FIRE.
RADIUS.
1,000 METRES.
100. M.
10. M.
10^-4 SECONDS
10^-3
TIME
10^-2
10^-1
1 SECON
I TRINITY
II BIKINI
MEASURED
ASSUMED
ASSUMED
III BIKINI
MEASURED
ASSUMED
Fig. 1

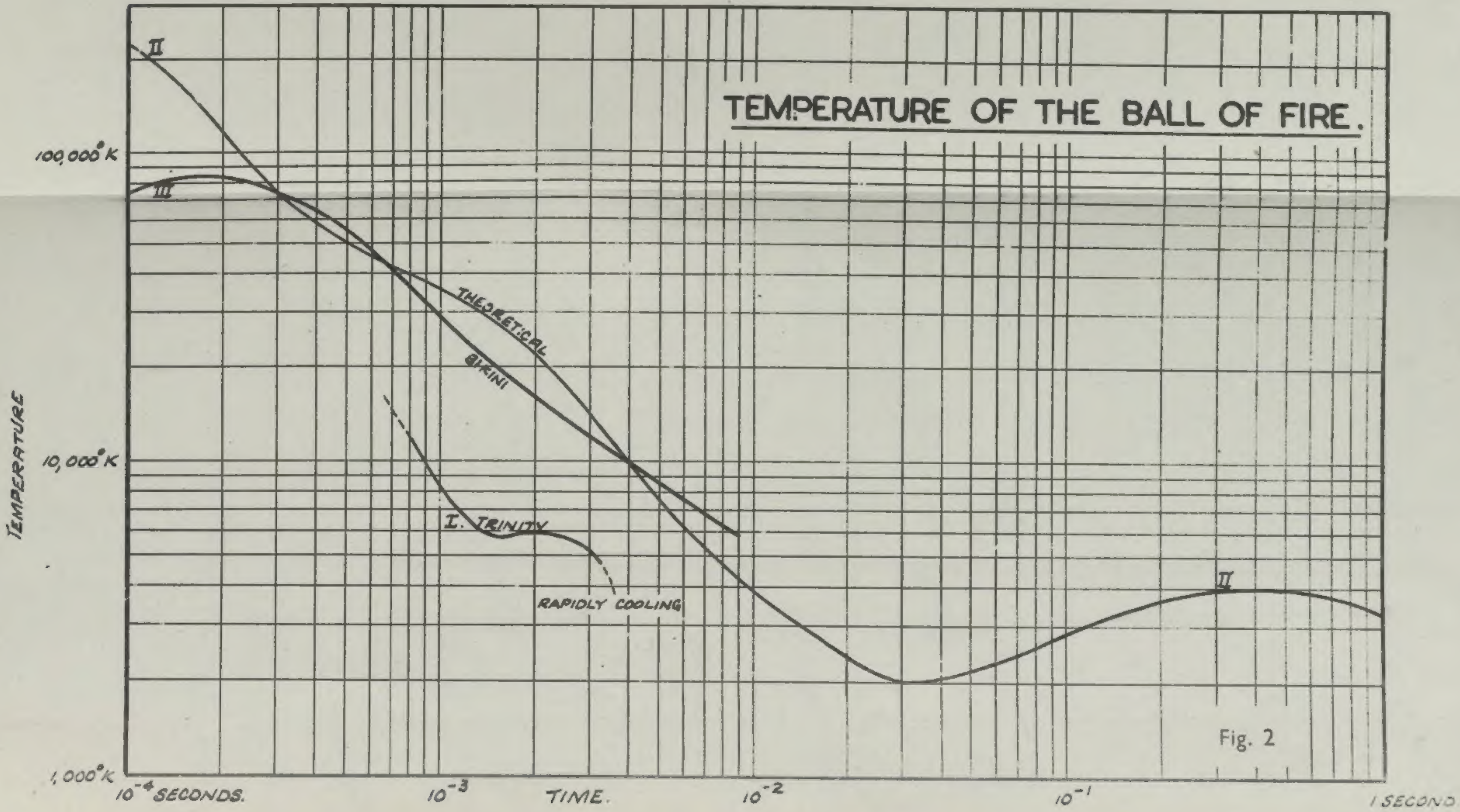

TEMPERATURE OF THE BALL OF FIRE.
TEMPERATURE
100,000°K
10,000°K
1,000°K
10^-4 SECONDS.
10^-3
TIME.
10^-2
10^-1
1 SECOND
II
III
THEORETICAL
BIKINI
I. TRINITY
RAPIDLY COOLING
II

Fig. 2

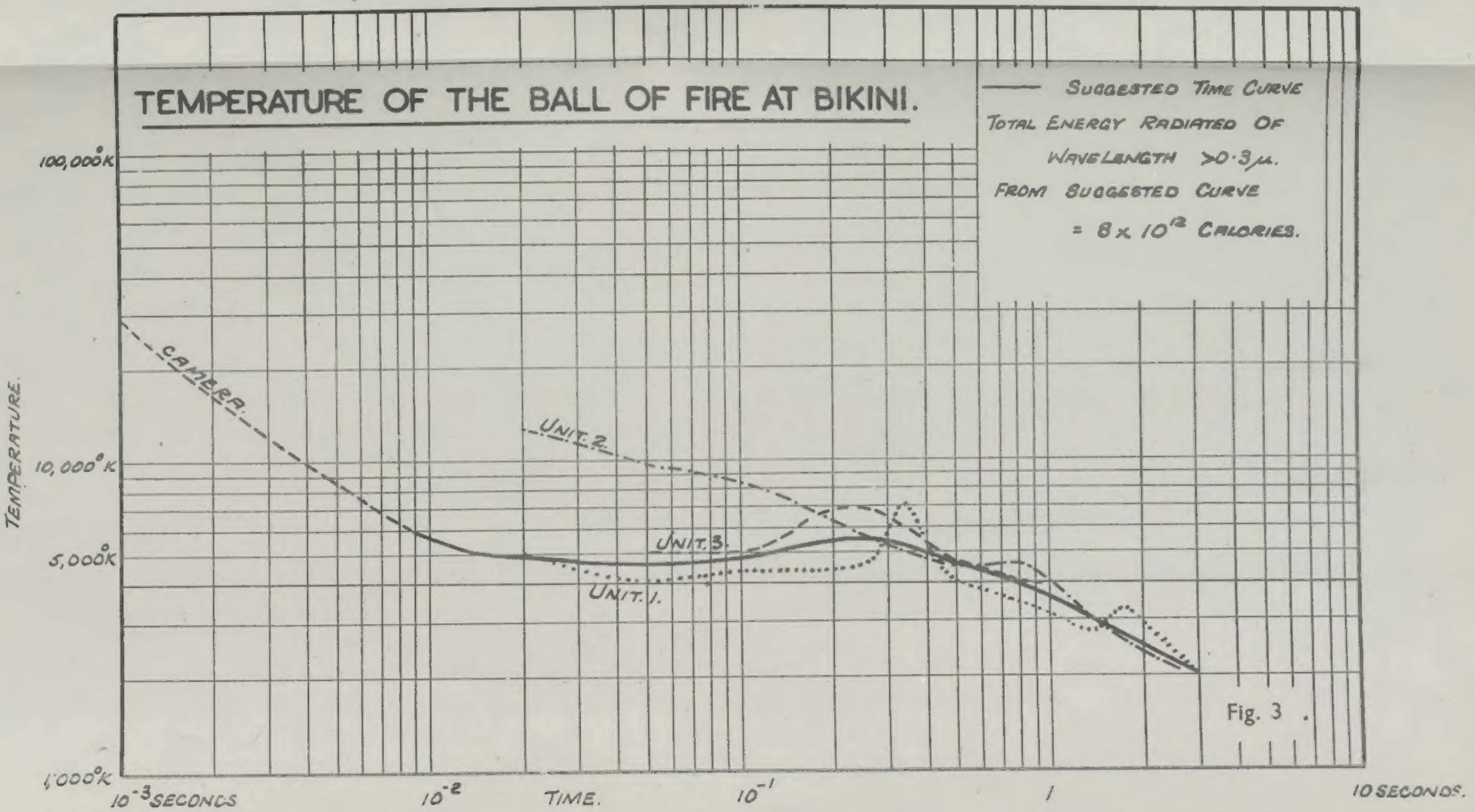
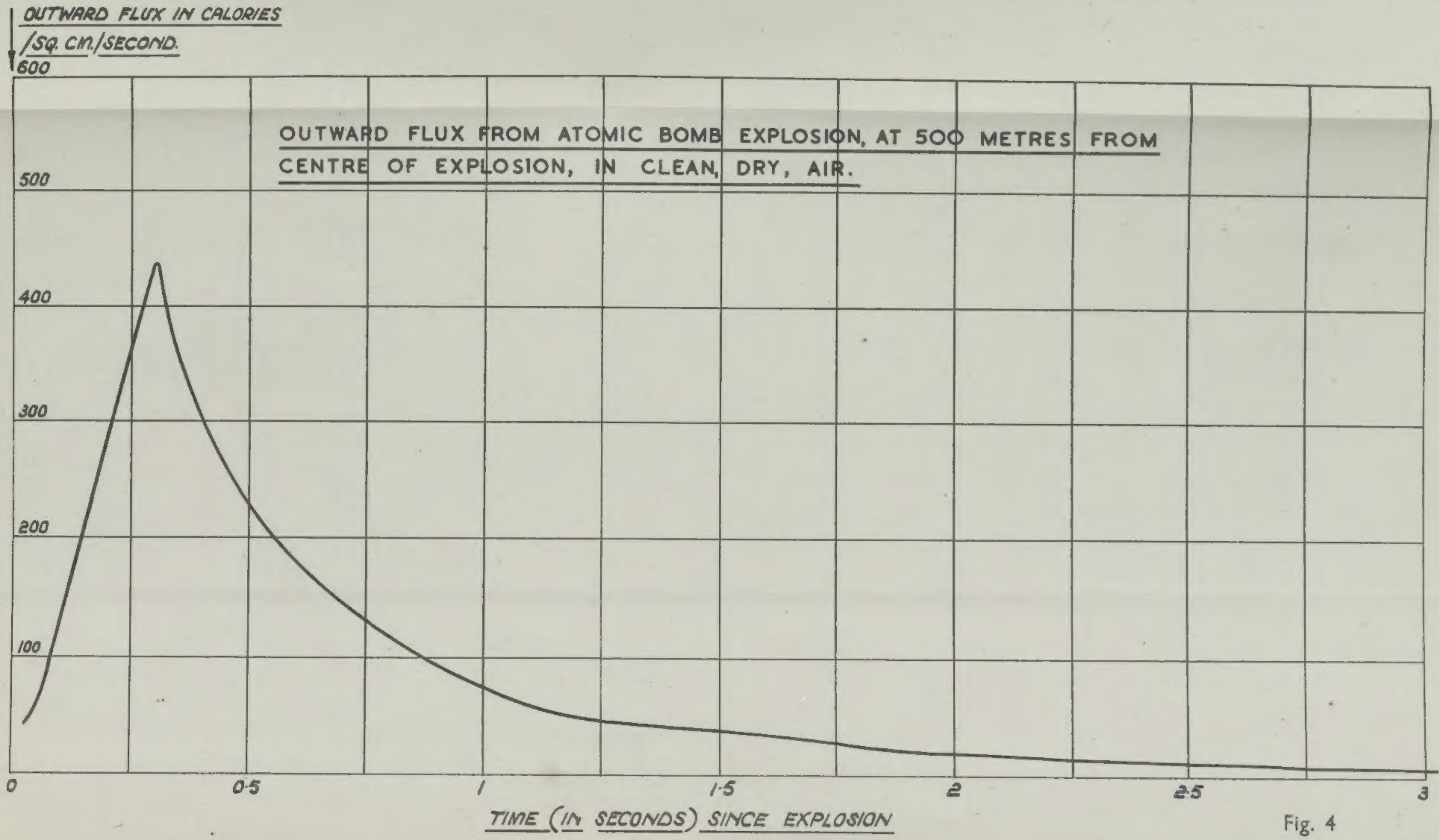

TEMPERATURE OF THE BALL OF FIRE AT BIKINI.
— SUGGESTED TIME CURVE
TOTAL ENERGY RADIATED OF WAVELENGTH >0·3μ. FROM SUGGESTED CURVE = 8 x 10^12 CALORIES.
TEMPERATURE.
100,000°K
10,000°K
5,000°K
1,000°K
CAMERA
UNIT. 2.
UNIT. 3.
UNIT. 1.
10^-3 SECONDS
10^-2
TIME.
10^-1
1
10 SECONDS.

Fig. 3 .



OUTWARD FLUX IN CALORIES /SQ. CM./SECOND.
600
500
400
300
200
100
0
0·5
1
1·5
2
2·5
3
OUTWARD FLUX FROM ATOMIC BOMB EXPLOSION, AT 500 METRES FROM CENTRE OF EXPLOSION, IN CLEAN, DRY, AIR.
TIME (IN SECONDS) SINCE EXPLOSION

Fig. 4